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Determinants of the quality of brazed joints of nickel-based superalloys

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Abstract

In the aerospace industry, passenger safety depends on proper quality control at each production stage. The main responsibility for the correct operation of the aircraft lies within a gas turbine. A proper and rigorous selection of the gas turbine construction material is required, and in a further step, the method of joining the construction parts. Nickel superalloys due to the high heat resistance, strength and creep resistance at high temperatures, toughness and corrosion resistance, are very often used for the construction of a gas turbine engine. In the next step, the selection of joining method is necessary. This method must be able to achieve high-quality connections, resistant to work at high temperatures and corrosive environments. The most effective bonding method that meets the above conditions is brazing. In this study non-destructive (visual) test and destructive (metallographic) test of brazed joint of Inconel 718 and Inconel 625 were conducted.

1. Introduction

Initially for the constructions of engines, steel and residual quantities of light metals alloys such as aluminum and magnesium were used. Only in the years 1960 - 1970 the application of nickel alloys in the structure of aircraft engines increased. It was due to the development of an innovative casting method, especially vacuum casting, which prevented the porosity in the castings which enabled the use of alloys not only in forgings but also in castings. Nowadays, the use of not only nickel alloys but also Ti and Al based composite materials is successfully used to build aircraft engines (Fig. 1). At low temperatures of up to 500°C, composites and light metals (Ti, Al) are used, because of their low density at relatively high strength properties. Therefore, their use reduces the mass of the engine and, thus, reduces fuel consumption. Above 500°C, nickel superalloys are used, mainly for the construction of combustion chambers, turbines and gas outlets, that is where heat-resistant and heat-resistant materials are required. In addition, there are high vibrations in these areas of the turbine engine, so the materials must have high fatigue strength. The temperature in the combustion chamber can reach up to 2000°C, so it is necessary to apply diffusion coatings or plasma spraying of thermal barriers. Materials must also be resistant to corrosion, which is the result of exposure to combustion products. In the aerospace industry the most commonly used nickel alloys are Inconel 718, Inconel 625 oraz Hastelloy X. In some cases also Udimet R41 and Nimonic 90 are used. All materials intended for use in the aerospace industry must be supplied by approved and reliable suppliers. In addition these materials are subject of very stringent quality control throughout their lifecycle.

The most commonly used connections in the aerospace industry include: glue, rivet, welded, brazed, threaded joints. The use of a particular connection depends on the following factors: the type of the materials to be combined, geometric dimensions of the components (in particular thickness), operating requirements, connection conditions, type of production and other (RUDAWSKA A., CISEK J., SEMOTIUK L. 2012).

Currently manufactured products are characterized by the use of advanced technological solutions with specific and unique properties, which forces the techniques to be used. For this reason, manufacturers choose brazing as the most effective bonding method. By choosing the properly brazing method and binding materials, the desired connection characteristics can be obtained.

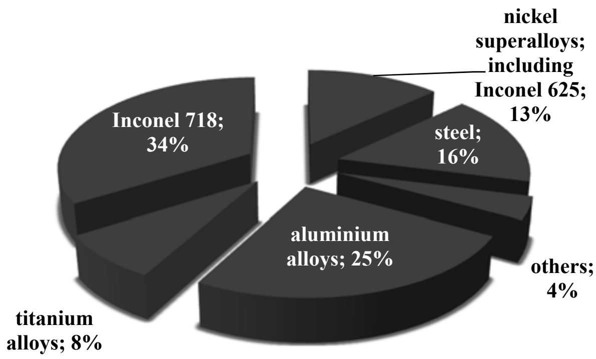

Fig 1. Percentage share of individual materials groups in theCF6 aircraft engine structure

The challenge is to combine dissimilar materials with different geometry and impossible to join with other methods (PIWOWARCZYK T., HARAPIŃSKA E., WOJDAT T. 2016). The basic process intended for bonding of nickel-based superalloys are hard brazing and high temperature brazing in a vacuum oven. However, in the aerospace industry, vacuum brazing is mainly used for the production of turbine engines (DUL I., SENKARA J., BOBER M., JAKUBOWSKI J. 2013). In paper of Aradin et al. the advantages of using brazed connections of nickel - based superalloys for aero - engine hot section components are presented (ARAFIN M.A., MEDRAJ M., TURNER D.P., BOCHER P. 2007). Brazed joints in vacuum oven are characterized by high precision, high strength and lack of oxide inclusions, dissolved gases and blisters. The limitation of this method is undoubtedly the necessity of having a specialized vacuum oven, but mainly in the brazing temperature (about 1050°C) between bonded components should be gap of a thickness 25÷175 μm. After heating the charge to a temperature of 800°C, to the chamber of the vacuum oven inert gas is supplied, in order to prevent sublimation of alloying elements in the braze material. The solder for vacuum brazing consists of such metals as Cu, Ag, Au, Ni, Co, Pt, Pd and their alloys, and has the shape of ring, wire, foil or powder (BIELNIAK J. 2002).

The formation of a brazed joint is a complex process, so strict quality control should be carried out not only on the final brazed joint but also at every stage of its production (KUCIA G., FIEGLER K. 2015). The processes associated with the formation of brazed joints are various physical phenomena and chemical reactions, including: reduction and dissociation of oxides covering the surface of metals and alloys, capillary phenomena, brazing crystallization, diffusion and mutual dissolution of a brazer and brazing material. The importance and impact of surface preparation method of Inconel 625 and 718 sheets on wettability of the surface, in high temperature vacuum brazing processes, are presented by Lankiewicz et al. research group (LANKIEWICZ K., BARANOWSKI M., BABUL T., KOWALSKI S. 2015) The wrong course of any of the above processes, due to, for example, improperly cleaned surface of the components, defective joint design, unsuitable binder and flux, unacceptable temperature and time of the brazing process, which can lead to non-conformance of brazer joints (RADOMSKI T., CISZEWSKI A. 1968). Incompatible brazer joints formed during hard brazering are described in standard PN-EN ISO 18279 „Lutowanie twarde – Niezgodności w złączach lutowanych na twardo". The brazer incompatibilities were classified in the following groups:

I. cracks,
II. emptiness,
III. permanent inclusions,
IV. no connection,
V. incompatibility of shape and dimension,
VI. different incompatibilities (WINIOWSKI A. 2012).

The quality control distinguishes destructive and non-destructive testing methods for brazed joints, which are described respectively in PN-EN 12797:2000 and PN-EN 12799:2000.

Table 1. Destructive and non-destructive tests of hard-brazered connections

Destructive tests PN-EN 12797	**Non-destructive tests PN-EN 12799**
• metallographic research	• visual research
• tensile strength test	• ultrasonic test
• hardness test	• radiographic test
• peel strength test	• penetration test
• flexural strength test	• leakage test
	• load test

Macroscopic studies allow to identify defects in brazer joints. Microscopic studies allow for the verification of the presence of microcracks, non-metallic inclusions, intermetallic gases and the evaluation of the structure of the brazer joint, the basic materials and the grain size. Other methods classified as destructive tests allow to determine the mechanical properties of the examined joints, and indicate the incompatibilities that affect these properties. Non-destructive testing is of utmost importance. Brazed joints can be tested for mechanical strength, electrical conductivity and tightness. The basis is visual research, which is then supplemented by other methods of testing the incompatibility of joints. In aerospace industry the leakage testing of elements that are in contact with liquids has a particular importance.

2. Experimental

Inconel 625 was brazed in a hole made in plate of Inconel 718. Solder consisted mainly of gold. Prior to the proper bonding process the surfaces of the materials were cleaned and degreased chemically. The brazing process was carried out in a vacuum oven.

Table 2. Chemical composition of Inconel 625 and Inconel 718

	Ni	Cr	Fe	Nb	Mo	Ti	Al	C
625	51.34	19.41	16.88	3.96	2.72	1.02	0.56	4.13
718	57.91	21.88	4.64	3.82	8.33	0.16	0.41	3.42

In the study, brazed joint with a stereoscopic microscope Olympus SZ31 was analyzed. JEOL JSM 5400 scanning electron microscope was used to determine the chemical composition of solder.

3. Results and discussion

In the Figure 2 macrostructures of obtained brazed joint are shown.

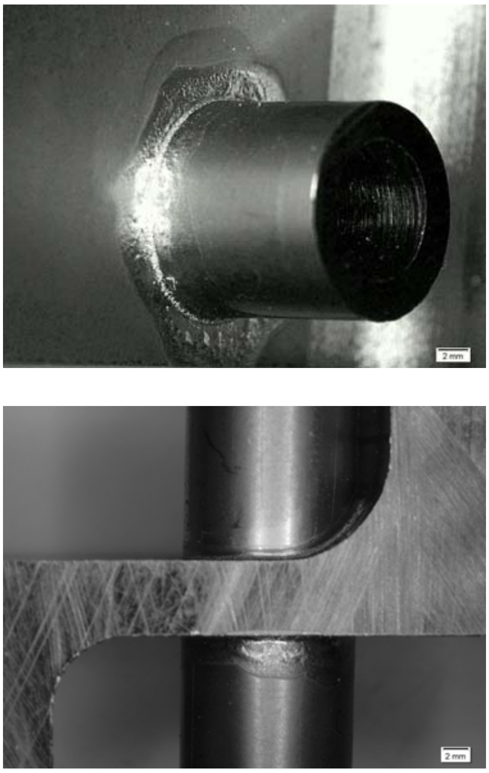

Fig 2. Macrostructure of brazed joint

The observations of these macrostructures revealed the absence of: dissipation of solder binder, porosity, flux insertion and cracks. In order to identify the chemical composition of the Inconel 625 nickel-alloy brazer tube and Inconel 718 plate, SEM-EDS analysis was performed. The results are shown in Figure 3 and Figure 4. The analysis revealed that the execution of the brazed connection did not cause partial melting of base materials, which at the same time prevented deformation of the structural components, which is also confirmed by macroscopic observations.

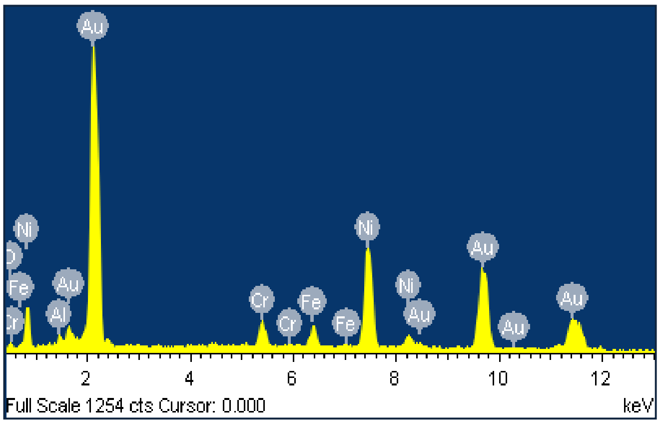

Fig 3. EDS spectrum of the brazed joint

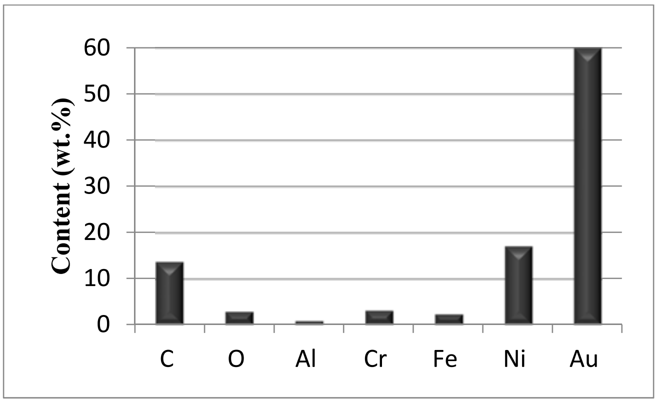

Fig 4. Chemical composition of brazed joint

4. Summary and conclusion

A priority of aerospace industry is to provide adequate reliability and safety. To meet these requirements, rigorous quality control is required at each production stage. The key point is to choose the right material, and in the next step, the joining method with other structural elements. A utilitarian aim is to plan the soldering process of selected materials, so that the resulting structure is devoid of deformation and structural defects, which are the basis for its disqualification in the aerospace industry.

Conducted non-destructive (visual) and metallographic (non-destructive) tests have shown that the brazing parameters selected for the Inconel 625 to Inconel 718 allowed for connection that meets the aerospace quality requirements.

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镍基超级合金钎焊接头质量的决定因素

關鍵詞
铜焊
铬镍铁合金625
铬镍铁合金718
航空航天工业
燃气轮机

摘要
在航空航天工业中，乘客安全取决于每个生产阶段的适当质量控制。 飞机正确操作的主要责任在燃气轮机内。 需要对燃气轮机构造材料进行适当且严格的选择，并且在另外的步骤中，连接构造部件的方法。 由于高耐热性，高温下的强度和抗蠕变性，韧性和耐腐蚀性，镍超级合金非常常用于燃气轮机的构造。 在下一步中，需要选择加入方法。 这种方法必须能够实现高质量的连接，耐高温和腐蚀性环境下工作。满足上述条件的最有效的接合方法是钎焊。 在本研究中，进行了Inconel 718和Inconel 625钎焊接头的非破坏性（视觉）试验和破坏性（金相）试验。